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PTO/SB/05 (2/98)  
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<b>UTILITY PATENT APPLICATION TRANSMITTAL</b> <small>(Only for new nonprovisional applications under 37 CFR 1.53(b))</small>		Attorney Docket No. 25821.P028
		First Inventor or Application Identifier Steve W.L. Yeung
Title AN EFFICIENT LIQUID CRYSTAL DISPLAY DRIVING SCHEME USING		
Express Mail Label No.		

PTO/SB/05  
10/02/00  
09/678058

<b>APPLICATION ELEMENTS</b> See MPEP chapter 600 concerning utility patent application contents		ADDRESS TO:	Assistant Commissioner for Patents Box Patent Application Washington, DC 20231
<p>1. <input checked="" type="checkbox"/> Fee Transmittal Form (e.g. PTO/SB/17) (Submit an original, and a duplicate for fee processing)</p> <p>2. <input type="checkbox"/> Specification Total Pages <input type="text"/></p> <ul style="list-style-type: none"> <li>- Descriptive title of the Invention</li> <li>- Cross References to Related Applications</li> <li>- Statement Regarding Fed sponsored R &amp; D</li> <li>- Reference to Microfiche Appendix</li> <li>- Background of the Invention</li> <li>- Brief Summary of the Invention</li> <li>- Brief Description of the Drawings (if filed)</li> <li>- Detailed Description</li> <li>- Claim(s)</li> <li>- Abstract of the Disclosure</li> </ul> <p>3. <input type="checkbox"/> Drawing(s) (35 U.S.C.113) Total Sheets <input type="text"/></p> <p>4. Oath or Declaration Total Pages <input type="text"/></p> <p>a. <input type="checkbox"/> Newly executed (original copy)</p> <p>b. <input type="checkbox"/> Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional with Box 16 completed)</p> <p>i. <input type="checkbox"/> <b>DELETION OF INVENTOR(S)</b> Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).</p>		<p>5. <input type="checkbox"/> Microfiche Computer Program (Appendix)</p> <p>6. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)</p> <p>a. <input type="checkbox"/> Computer Readable Copy</p> <p>b. <input type="checkbox"/> Paper Copy (identical to computer copy)</p> <p>c. <input type="checkbox"/> Statement verifying identity of above copies</p>	
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Prior application Information: Examiner \_\_\_\_\_ Group/Art Unit: \_\_\_\_\_

For **CONTINUATION** or **DIVISIONAL APPS** only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

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 Small Entity payments must be supported by a small entity statement,  
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 See 37 C.F.R. §§ 1.28 and 1.28

TOTAL AMOUNT OF PAYMENT (\$)

710.00

**Complete if Known**

Application Number	
Filing Date	
First Named Inventor	Steve W.L. Yeung, et al.
Examiner Name	
Group Art Unit	
Attorney Docket Number	25821.P028

**METHOD OF PAYMENT** (check one)

1.  The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:

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**FEE CALCULATION** (fees effective 10/01/96)**1. FILING FEE**

## Large Entity Small Entity

Fee Code	Fee (\$)	Fee Code	Fee (\$)	Fee Description	Fee Paid
101	690	201	345	Utility filing fee	<span style="border: 1px solid black; padding: 2px;">710</span>
106	310	206	155	Design filing fee	
107	480	207	240	Plant filing fee	
108	690	208	345	Reissue filing fee	
114	150	214	75	Provisional filing fee	
<b>SUBTOTAL (1)</b>		<b>(\$)</b>		<b>710.00</b>	

**2. EXTRA CLAIM FEES**

Total Claims	Extra Claims	Fee from below	Fee Paid
13	-20** = 0	X	= 0.00
1	-3** = 0	X	= 0.00
Multiple Dependent			

\*\* or number of previously paid, if greater; For Reissues, see below

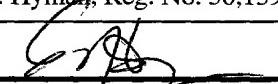
## Large Entity Small Entity

Fee Code	Fee (\$)	Fee Code	Fee (\$)	Fee Description
103	18	203	9	Claims in excess of 20
102	78	202	39	Independent claims in excess of 3
104	270	204	135	Multiple Dependent claim
109	78	209	39	**Reissue independent claims over original patent
110	18	210	9	**Reissue claims in excess of 20 and over original patent
<b>SUBTOTAL (2)</b>		<b>(\$)</b>		<b>0.00</b>

\* Reduced by Basic Filing Fee Paid

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AN EFFICIENT LIQUID CRYSTAL  
DISPLAY DRIVING SCHEME USING  
ORTHOGONAL BLOCK-CIRCULANT MATRIX

The invention relates to a protocol for driving a liquid crystal display, particularly to a driving scheme of liquid crystal display, and more particularly to a special arrangement of the entries of the driving matrix, which results in an efficient implementation of the scheme and a reduction in hardware complexity.

Passive matrix driving scheme is commonly adopted for driving a liquid crystal display. For those high-mux displays with liquid crystals of fast response, the problem of loss of contrast due to frame response is severe. To cope with this problem, active addressing was proposed in which an orthogonal matrix is used as the common driving signal. However, the method suffers from the problem of high computation and memory burden. Even worse, the difference in sequences of the rows of matrix results in different row signal frequencies. This may result in severe crosstalk problems. On the other hand, Multi-Line-Addressing (MLA) was proposed, which makes a compromise between frame response, sequency, and computation problems. The block-diagonal driving matrix is made up of lower order orthogonal matrices. To further suppress the frame response, column interchanges of the driving matrix were suggested in such a way that the selections are evenly distributed among the frame. The complexity of the scheme is proportional to square of the order of the building matrix. Increase of order of the scheme results in complexity increase in both time and spatial domains. The order

increase asks for more logic hardware and voltage levels of the column signal.

According to the invention there is provided a protocol for driving a liquid crystal display, characterised in that a row (common) driving matrix consists of orthogonal block-circulant matrices.

### Liquid Crystal Driving Scheme Using Orthogonal Block-Circulant Matrix

The following shows an order-8 Hadamard matrix.

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$$

As mentioned in the foregoing, because of the computation burden and sequency problem of using active driving, MLA was proposed. To implement an 8-way drive by using 4-line MLA, two order-4 Hadamard matrices are used as the diagonal building blocks of the 8x8 driving matrix. The resulting common driving matrix is as follows:

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 \\ 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & -1 & 1 & -1 \\ 0 & 0 & 0 & 0 & 1 & 1 & -1 & -1 \\ 0 & 0 & 0 & 0 & 1 & -1 & -1 & 1 \end{bmatrix}$$

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To minimize the sequency problem, another 4x4 orthogonal building block has been proposed. The resulting row (common) driving matrix is as follows:

$$\begin{bmatrix} -1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & -1 & 1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & -1 & 1 \\ 0 & 0 & 0 & 0 & 1 & -1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & -1 \end{bmatrix}$$

A general  $m$ -Way display will have a  $m \times m$  block diagonal orthogonal driving matrix made up of  $m/4$  (assuming that  $m$  is an integer multiple of 4) 4x4 building blocks. The actual voltage applied is not necessary  $\pm 1$  but a constant multiple of the value (i.e.,  $\pm k$ ). To further suppress the frame response, it has been proposed that column interchanges of the row (common) driving matrix such that the selections are evenly distributed among the frame. Using the 8-way drive as example, the following row (common) driving matrix results:

$$\begin{bmatrix} -1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & -1 & 0 & 1 & 0 \\ 1 & 0 & -1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & -1 & 0 \\ 0 & -1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & -1 & 0 & 1 \\ 0 & 1 & 0 & -1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & -1 \end{bmatrix}$$

In the invention, there is proposed a method of generating orthogonal block-circulant building blocks that result in reduced hardware complexity of the driving circuitry. First of all, an orthogonal block-circulant matrix is defined as follows:

*Definition: An  $NM \times NM$  block-circulant matrix  $B$  consisting of  $NM \times M$  building blocks  $A_1, A_2, \dots, A_N$  is of the form*

$$B = \begin{bmatrix} A_1 & A_2 & \cdots & A_N \\ A_N & A_1 & \cdots & A_{N-1} \\ M & M & O & M \\ A_2 & A_3 & \cdots & A_1 \end{bmatrix}$$

*It is said to be an orthogonal block-circulant if  $R^T R = R R^T = NM I_{NM}$ .*

For example, the following  $4 \times 4$  matrix is orthogonal block-circulant

In this case,  $N$  can be 2 or 4. If  $N=2$ , then each  $A_j$  is  $2 \times 2$  matrix. If  $N=4$ , then each  $A_j$  is

$$\begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix}$$

a scalar (1 or -1). The orthogonal block-circulant matrix can be used as the diagonal building block of a row (common) driving matrix. By proper column and row interchanges, the resulting driving matrix has a property that each row is a shifted version of preceding rows and can be implemented by using shift registers. The following shows the resulting 8-way drive using  $4 \times 4$  orthogonal block-circulant matrix after suitable row and column interchanges.

$$\begin{bmatrix} -1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & -1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & -1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & -1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & -1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & -1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & -1 \end{bmatrix}$$

For higher order  $B$ , the choice of the order of sub-block  $A_i$  is limited. Some  $M$  might result in nonexistence of orthogonal block-circulant  $B$ . Let  $MN=6$ , then  $M$ , the order of sub-block, can be 1, 2, or 3. It can be shown that orthogonal block-circulant  $B$  can be achieved by  $M=2, 3$ , but not  $M=1$ . In general, given that  $MN$  is even, it can be shown that orthogonal block-circulant  $B$  always exists provided that  $M \neq 1$ . In the following, two means of generating orthogonal block-circulant matrices are proposed.

The first method is based on theory of *paraunitary matrix* but it by no means generates all orthogonal block-circulant matrices. The second method is a means to identify orthogonal block-circulant matrices by nonlinear programming. Theoretically, it can be used to generate all orthogonal block-circulant matrices.

### Generation of Orthogonal Block-Circulant Matrix Using Paraunitary Matrix

Consider order  $MnNm$  sub-matrix of  $B$  as follows:

$$\Sigma = [A_1 \ A_2 \ \dots \ A_M]$$

Define  $n \times n$  shift matrix  $S_{n,m}$  as follows

$$S_{n,m} = \begin{bmatrix} 0 & I_{n \times n} \\ 0_{(n-m) \times (n-m)} & 0 \end{bmatrix}$$

A paraunitary matrix  $E$  of order  $MnNm$  satisfies

(i)  $E$  is orthogonal i.e.,

$$\underline{EE^T = I}$$

(ii)  $E$  is orthogonal to its column shift by multiples of  $M$  i.e.,

$$\underline{E S_{M,n} E^T = 0}$$

for  $i = 1, 2, \dots, M-1$ .

In general, paraunitary matrices can be represented in a cascade lattice form with rotational angles as parameters.

The following two are two example 2x4 paraunitary matrices.

$$E_1 = \begin{bmatrix} 1 & 1 & -1 & 1 \\ -1 & -1 & -1 & 1 \end{bmatrix}$$

$$E_2 = \begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \end{bmatrix}$$

We have the following property of paraunitary matrices:

*Property: B generated by block-circulating paraunitary E is orthogonal*

*Proof: Define nxn recurrent shift matrix R<sub>n,m</sub> as follows*

An orthogonal block-circulant matrix B of order NMxNM with MxM sub-matrix E satisfies

(i) E is orthogonal i.e.,

$$EE^T = I$$

(ii) E is orthogonal to its recurrent shift by multiples of M i.e.,

$$ER_{(N-1)M,M} E^T = 0$$

for  $i = 1, 2, \dots, N-1$ .

Provided that E is paraunitary, as

$$R_{n,m} = S_{n,m} + S_{n-m,n-m}^T$$

we have

$$ER_{(N-1)M,M} E^T = E(S_{n,m} + S_{n-m,n-m}^T)E^T = ES_{n,m}E^T + ES_{n-m,n-m}^TE^T = 0$$

and that completes the proof. Notice that E is paraunitary is a sufficient but not necessary condition for B to be orthogonal block-circulant. Using E<sub>1</sub> and E<sub>2</sub> as building blocks, we obtain the following orthogonal block-circulant matrices.

$$B_1 = \begin{bmatrix} 1 & 1 & -1 & 1 \\ -1 & -1 & -1 & 1 \\ -1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \end{bmatrix}$$

$$B_2 = \begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix}$$

Notice that  $B_2$  is orthogonal circulant as well as orthogonal block-circulant. As illustrated before, by using it as the building block of row (common) driving matrix with suitable row and column interchanges, each row is a delay-1 shifted version of preceding row. However,  $B_1$  is orthogonal block-circulant but it is not circulant. By suitable row and column interchanges of the resulting driving matrix, two sets of row (common) driving waveforms are obtained. Within a set, each row is a shifted version of the others.

The complexity of implementation is proportional to the order of the sub-blocks  $A_j$  (i.e.,  $M$ ). For  $MM=4$ , we observe that  $M$  can be 1 or 2. For higher order,  $M=1$  does not result in any circulant  $B$  that is orthogonal. Provided  $M=2$ , orthogonal block-circulant  $B$  always exists and can be generated by  $2x2N$  paraunitary matrices. The driving matrix resulted from  $B_1$  with suitable column interchanges is shown below:

$$\begin{bmatrix} 1 & 0 & 1 & 0 & -1 & 0 & 1 & 0 \\ -1 & 0 & -1 & 0 & -1 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & -1 & 0 & -1 & 0 \\ 0 & 1 & 0 & 1 & 0 & -1 & 0 & 1 \\ 0 & -1 & 0 & -1 & 0 & -1 & 0 & 1 \\ 0 & -1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & -1 & 0 & 1 & 0 & -1 & 0 & -1 \end{bmatrix}$$

Rows 1, 3, 5, 7 and 2, 4, 6, 8 form the two sets within which each row is a shifted version of the others.

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### Generation of Orthogonal block-circulant Matrix by Nonlinear Programming

An orthogonal block-circulant matrix can be generated by nonlinear programming. The method of steepest descent illustrates this. The method of steepest descent is widely used in the identification of complex and nonlinear systems. The update law identifying sub-matrix  $E$  can be stated as follows:

$$E_{n+1} = E_n + \delta \frac{\nabla P}{\| \nabla P \|}$$

where  $\delta$  is the step size.  $P$  is the cost or penalty function. We set  $P$  as follows:

$$P(E) = \sum_i (e_i^2 - 1)^2 + \|EE^T - I\|_F^2 + \sum_i \|ER_{ii} - E^T\|_F^2$$

$e_i$  are the entries of  $E$ .  $\| \cdot \|_F$  is the Frobenius norm of a matrix. The first summation in the function forces all the entries of  $E$  to be  $\pm 1$ . The second one forces  $E$  to be orthogonal, while the third summation ensures orthogonal block-circulant property of the resulting  $B$ .

List of Order-4 and Order-8 Orthogonal Block-Circulant Matrices  
The following is an exhaustion of all 2x4 and 2x8 sub-matrices  $E$  with entries  $\pm 1$  that result in orthogonal block-circulant building blocks.

#### Order-4

(1)

$$\begin{bmatrix} 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix}$$

(2)

$$\begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix}$$

(3)

$$\begin{bmatrix} -1 & 1 & -1 & -1 \\ 1 & 1 & -1 & 1 \end{bmatrix}$$

(4)

$$\begin{bmatrix} -1 & -1 & -1 & 1 \\ 1 & 1 & -1 & 1 \end{bmatrix}$$

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(5) all alternatives of (1)-(4) generated by

- (i) sign inversion (i.e.,  $\bar{E}$ );
- (ii) row interchange, i.e.,

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} E;$$

(iii) circulant shift of  $E$ , i.e.,

$$ER_{4,2}$$

and any combinations of (i)-(iii).

### Order-8

(1)

$$\begin{bmatrix} 1 & 1 & -1 & 1 & 1 & -1 & 1 & 1 \\ 1 & 1 & 1 & -1 & 1 & -1 & -1 & -1 \end{bmatrix}.$$

(2)

$$\begin{bmatrix} 1 & 1 & 1 & -1 & 1 & -1 & -1 & -1 \\ 1 & 1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}.$$

(3)

(4)

(5)

(6)

$$\begin{bmatrix} 1 & 1 & -1 & 1 & -1 & 1 & -1 & -1 \\ 1 & 1 & 1 & -1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & -1 & 1 & 1 \end{bmatrix}.$$

(7)

(3)

$$\overline{\int_{\mathbb{R}^d} \frac{1}{|x-y|^{d-\alpha}} f(y) dy} = \int_{\mathbb{R}^d} \frac{1}{|x-y|^{d-\alpha}} f(y) dy$$

(9)

$$\left[ \begin{array}{ccccc} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 1 \end{array} \right] = \frac{1}{5!} \cdot \left[ \begin{array}{ccccc} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 1 \end{array} \right]$$

(10)

$$\begin{bmatrix} -1 & 1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix}.$$

(13)

(12)

$\frac{1}{n}$	$\frac{1}{n+1}$	$\frac{1}{n+2}$	$\frac{1}{n+3}$	$\frac{1}{n+4}$	$\frac{1}{n+5}$	$\frac{1}{n+6}$	$\frac{1}{n+7}$	$\frac{1}{n+8}$	$\frac{1}{n+9}$
$\frac{1}{n}$	$\frac{1}{n+1}$	$\frac{1}{n+2}$	$\frac{1}{n+3}$	$\frac{1}{n+4}$	$\frac{1}{n+5}$	$\frac{1}{n+6}$	$\frac{1}{n+7}$	$\frac{1}{n+8}$	$\frac{1}{n+9}$
$\frac{1}{n}$	$\frac{1}{n+1}$	$\frac{1}{n+2}$	$\frac{1}{n+3}$	$\frac{1}{n+4}$	$\frac{1}{n+5}$	$\frac{1}{n+6}$	$\frac{1}{n+7}$	$\frac{1}{n+8}$	$\frac{1}{n+9}$
$\frac{1}{n}$	$\frac{1}{n+1}$	$\frac{1}{n+2}$	$\frac{1}{n+3}$	$\frac{1}{n+4}$	$\frac{1}{n+5}$	$\frac{1}{n+6}$	$\frac{1}{n+7}$	$\frac{1}{n+8}$	$\frac{1}{n+9}$
$\frac{1}{n}$	$\frac{1}{n+1}$	$\frac{1}{n+2}$	$\frac{1}{n+3}$	$\frac{1}{n+4}$	$\frac{1}{n+5}$	$\frac{1}{n+6}$	$\frac{1}{n+7}$	$\frac{1}{n+8}$	$\frac{1}{n+9}$
$\frac{1}{n}$	$\frac{1}{n+1}$	$\frac{1}{n+2}$	$\frac{1}{n+3}$	$\frac{1}{n+4}$	$\frac{1}{n+5}$	$\frac{1}{n+6}$	$\frac{1}{n+7}$	$\frac{1}{n+8}$	$\frac{1}{n+9}$

(15)

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

(7-1)

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

(15)

$$\begin{bmatrix} 1 & -1 & -1 & 1 & -1 & -1 & -1 & -1 & -1 \\ -1 & 1 & 1 & -1 & 1 & -1 & -1 & -1 & -1 \end{bmatrix} \xrightarrow{\text{Row Reduction}} \dots$$

(16)

$$\left[ \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}, \frac{v}{\sqrt{1-\frac{v^2}{c^2}}}, 0, \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \right]$$

(17)

$$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

(18)

- 11 -

(19)

$$\begin{bmatrix} 1 & 1 & 1 & -1 & 1 & 1 & -1 & 1 \\ -1 & 1 & 1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix}$$

(20)

$$\begin{bmatrix} 1 & 1 & -1 & 1 & 1 & 1 & 1 & -1 \\ 1 & -1 & 1 & 1 & 1 & -1 & -1 & 1 \end{bmatrix}$$

(21)

(22)

(23)

(24)

$$\begin{bmatrix} -1 & 1 & 1 & 1 & 1 & -1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 \\ 1 & 1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & 1 & -1 & 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

(25)

(26)

(27)

$$\begin{bmatrix} 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 1 & 1 & 1 & -1 & 1 & -1 & 1 \end{bmatrix}$$

(28) all alternatives of (1)-(27) generated by

- (i) sign inversion (i.e.,  $\bar{E}$ );
- (ii) row interchange, i.e.,

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} E;$$

- (iii) circulant shift of  $E$ , i.e.,

$$ER_{s,z}$$

$s=1, 2, \text{ or } 3$ , and any combinations of (i)-(iii)

Thus using the invention a special arrangement of the entries of driving matrix is proposed. By imposing orthogonal block-circulant property to the building blocks of the row (common) driving waveform, the row signals can be made to differ by time shifts only. Each row can now be implemented as a shifted version of preceding rows by using shift registers. The complexity of the matrix driving scheme is greatly reduced and is linearly proportional to the order of the orthogonal block-circulant building block.

**WE CLAIM:**

1. A protocol for driving a liquid crystal display, comprising:-
  - (i) a row (common) driving matrix; said matrix
  - (ii) consisting of orthogonal block-circulant matrices.
2. A protocol as defined in Claim 1, wherein there are row and column interchanges of said row (common) driving matrix.
3. A protocol as defined in Claim 1, wherein said row (common) driving matrix is an orthogonal block-circulant matrix.
4. A protocol as defined in Claim 1, wherein said row (common) driving matrix is a block diagonal matrix and wherein all the building blocks are orthogonal block-circulant.
5. A protocol as defined in Claim 4, wherein said row (common) driving matrix is a row and column interchanged version of the row (common) driving matrix.
6. A protocol as defined in Claim 1, wherein said row (common) driving matrix comprises orthogonal block-circulant building blocks generated by using a paraunitary matrix.

7. A protocol as defined in Claim 6, wherein said driving matrix is

$$\begin{bmatrix} 1 & 0 & 1 & 0 & -1 & 0 & 1 & 0 \\ -1 & 0 & -1 & 0 & -1 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & -1 & 0 & -1 & 0 \\ 0 & 1 & 0 & 1 & 0 & -1 & 0 & 1 \\ 0 & -1 & 0 & -1 & 0 & -1 & 0 & 1 \\ 0 & -1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & -1 & 0 & 1 & 0 & -1 & 0 & -1 \end{bmatrix}$$

8. A protocol as defined in Claim 1, wherein said row (common) driving matrix is based on orthogonal block-circulant building blocks generated by nonlinear programming.

9. A protocol as defined in Claim 8, wherein said row (common) driving matrix is based on order-4 orthogonal block-circulant building blocks.

10. A protocol as defined in Claim 8, wherein said row (common) driving matrix is based on order-8 orthogonal block-circulant building blocks.

11. A protocol as defined in Claim 9, wherein said building blocks comprise

(1)

$$\begin{bmatrix} 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix};$$

(2)

$$\begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix};$$

(3)

$$\begin{bmatrix} -1 & 1 & -1 & -1 \\ 1 & 1 & -1 & 1 \end{bmatrix};$$

(4)

$$\begin{bmatrix} -1 & -1 & -1 & 1 \\ 1 & 1 & -1 & 1 \end{bmatrix};$$

(5) all alternatives of (1)-(4) generated by

- (i) sign inversion (i.e.,  $-E$ );
- (ii) row interchange, i.e.,

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} E;$$

- (iii) circulant shift of  $E$ , i.e.,

$$EP_{4,2}$$

and any combinations of (i)-(iii).

12. A protocol as defined in Claim 10, wherein said building blocks comprise

(1)

$$\begin{bmatrix} 1 & 1 & -1 & 1 & 1 & -1 & 1 & 1 \\ 1 & 1 & 1 & -1 & 1 & -1 & -1 & -1 \end{bmatrix},$$

(2)

$$\begin{bmatrix} 1 & 1 & 1 & -1 & 1 & -1 & -1 & -1 \\ 1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix},$$

(3)

$$\begin{bmatrix} 1 & 1 & -1 & -1 & -1 & 1 & -1 & -1 \\ 1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix},$$

(4)

$$\begin{bmatrix} 1 & 1 & -1 & 1 & -1 & 1 & -1 & -1 \\ 1 & 1 & 1 & 1 & 1 & -1 & -1 & 1 \end{bmatrix},$$

(5)

$$\begin{bmatrix} -1 & 1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \end{bmatrix},$$

(6)

$$\begin{bmatrix} -1 & 1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \end{bmatrix},$$

(7)

$$\begin{bmatrix} -1 & 1 & -1 & 1 & 1 & 1 & -1 & -1 \\ 1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix},$$

(8)

$$\begin{bmatrix} -1 & 1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \end{bmatrix},$$

(9)

$$\begin{bmatrix} -1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 \\ 1 & 1 & -1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix},$$

(10)

$$\begin{bmatrix} -1 & 1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix};$$

(11)

$$\begin{bmatrix} -1 & 1 & 1 & -1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix};$$

(12)

$$\begin{bmatrix} 1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \end{bmatrix};$$

(13)

$$\begin{bmatrix} 1 & -1 & -1 & 1 & 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \end{bmatrix};$$

(14)

$$\begin{bmatrix} 1 & -1 & 1 & -1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \end{bmatrix};$$

(15)

$$\begin{bmatrix} 1 & -1 & -1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & 1 & -1 & 1 & -1 & -1 & -1 \end{bmatrix};$$

(16)

$$\begin{bmatrix} 1 & -1 & 1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & 1 & 1 & 1 & -1 & -1 & 1 \end{bmatrix};$$

(17)

$$\begin{bmatrix} 1 & -1 & 1 & 1 & 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 & 1 & -1 & -1 & -1 \end{bmatrix};$$

(18)

$$\begin{bmatrix} 1 & 1 & -1 & 1 & 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix};$$

(19)

$$\begin{bmatrix} 1 & 1 & 1 & -1 & 1 & 1 & -1 & 1 \\ -1 & 1 & 1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix};$$

(20)

$$\begin{bmatrix} 1 & 1 & -1 & 1 & 1 & 1 & 1 & -1 \\ 1 & -1 & 1 & 1 & 1 & -1 & -1 & -1 \end{bmatrix};$$

(21)

$$\begin{bmatrix} 1 & 1 & 1 & -1 & 1 & 1 & -1 & 1 \\ 1 & -1 & 1 & 1 & 1 & -1 & -1 & -1 \end{bmatrix};$$

(22)

$$\begin{bmatrix} -1 & 1 & 1 & 1 & 1 & -1 & 1 & 1 \\ -1 & 1 & 1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix};$$

(23)

$$\begin{bmatrix} -1 & -1 & -1 & 1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix};$$

(24)

$$\begin{bmatrix} -1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ -1 & 1 & 1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix};$$

(25)

$$\begin{bmatrix} 1 & -1 & 1 & 1 & -1 & 1 & 1 & 1 \\ -1 & 1 & 1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix};$$

(26)

$$\begin{bmatrix} 1 & -1 & -1 & -1 & -1 & 1 & -1 & -1 \\ -1 & 1 & 1 & 1 & -1 & 1 & -1 & -1 \end{bmatrix};$$

(27)

$$\begin{bmatrix} 1 & -1 & 1 & -1 & 1 & 1 & -1 & -1 \\ -1 & 1 & 1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix};$$

(28) all alternatives of (1)-(27) generated by

- (i) sign inversion (i.e.,  $-E$ );
- (ii) row interchange, i.e.,

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} E;$$

- (iii) circulant shift of  $E$ , i.e.,

$$ER_{3,2i}$$

$i=1, 2$ , or  $3$ , and any combinations of (i)-(iii)

13. A liquid crystal display, wherein there is a driving scheme, and a protocol as defined in Claim 1.

**ABSTRACT OF THE DISCLOSURE**

The invention relates to a protocol for driving a liquid crystal display, in which a row (common) matrix is made up of orthogonal block-circulant matrices which can be generated by nonlinear programming or alternatively by paraunitary matricing.